Fuel 216 (2018) 722–733

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Effect of hole pattern on the structure of small scale perorated plate burner flames

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ARTICLE INFO

Keywords:
Perforated plate
Three dimensional
Laminar-premixed flames
Configuration
Methane

ABSTRACT

A numerical study on the structure of the laminar premixed flames established on perforated plate burners is performed. Three dimensional numerical simulations are performed on different perforated plate geometries, under various operating conditions, using methane reaction mechanism consisting 36 species and 253 reactions. The comparison of numerical results of inline and staggered configurations of perforated plate burner models show that the flame interaction has significant role in the structure and stabilization of perforated burner flame. The flame structure, flame height and the standoff distances are studied for both inline and staggered configurations at fuel lean and rich conditions. The flame standoff distance and the flame height found to be higher for staggered configuration in comparison to the inline configuration. The flame structure is studied for different hole-to-hole distances. The numerical results show an increase in flame base curvature with an increase in hole-to-hole distance for both inline and staggered configurations. The flame thickness reduces with an increase in hole-to-hole distance for both inline and staggered cases. The effect of recirculation and flame base curvature causes the flame base to get stabilized at a higher distance in staggered configuration in comparison to the inline configuration.

1. Introduction

Perforated-plate burners are extensively used in industrial and household appliances. In these burners, several conical premixed flames are stabilized downstream of the perforated-plate. Since the premixed flames undergo problems like quenching, flash back and blow off, it is of utmost interest to understand the conditions at which flame can be stabilized.

Numerical, analytical and experimental investigations of the steady and dynamic properties of such premixed systems have been attempted [1–16]. Kim et al. [3] experimentally studied the dependence of liftoff height and propagation velocity with the mixture concentration gradient using a multi-slot burner configuration. It was observed that the liftoff flames could be stabilized successfully within a uniform velocity field having small concentration gradients. Lacour et al. [12] performed experimental investigations on the stability of partially premixed flames for a commercial gas cooking burner. They studied the blow-out phenomenon by varying inlet velocity and the burner geometry. An upper double flame and a lower double flame were observed, both of which showed different behaviour at blow-out region. Lee et al. [13] conducted an experimental study on the feasibility of LFG (Landfill gas)-LPG (liquefied petroleum gas) blended fuels on domestic burners. A flame stability diagram was also proposed by Lee et al. [14] for predicting the stable flame zone for partially premixed flames, in terms of heat input rate and equivalence ratio.

Mallens and de Goey [15] experimentally and numerically studied the stabilization of laminar methane-air flame on slit and tube burners near blow off region. The numerical simulation was performed using a single step reaction model. This study revealed the significance of critical velocity gradient in burner design. Mallens et al. [16] extended their studies for analysing the M-shape and V-shaped flames formed on a double-slit burner. By comparing with experimental results, they

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https://doi.org/10.1016/j.fuel.2017.12.057
Received 17 March 2017; Received in revised form 11 December 2017; Accepted 13 December 2017
0016-2361/

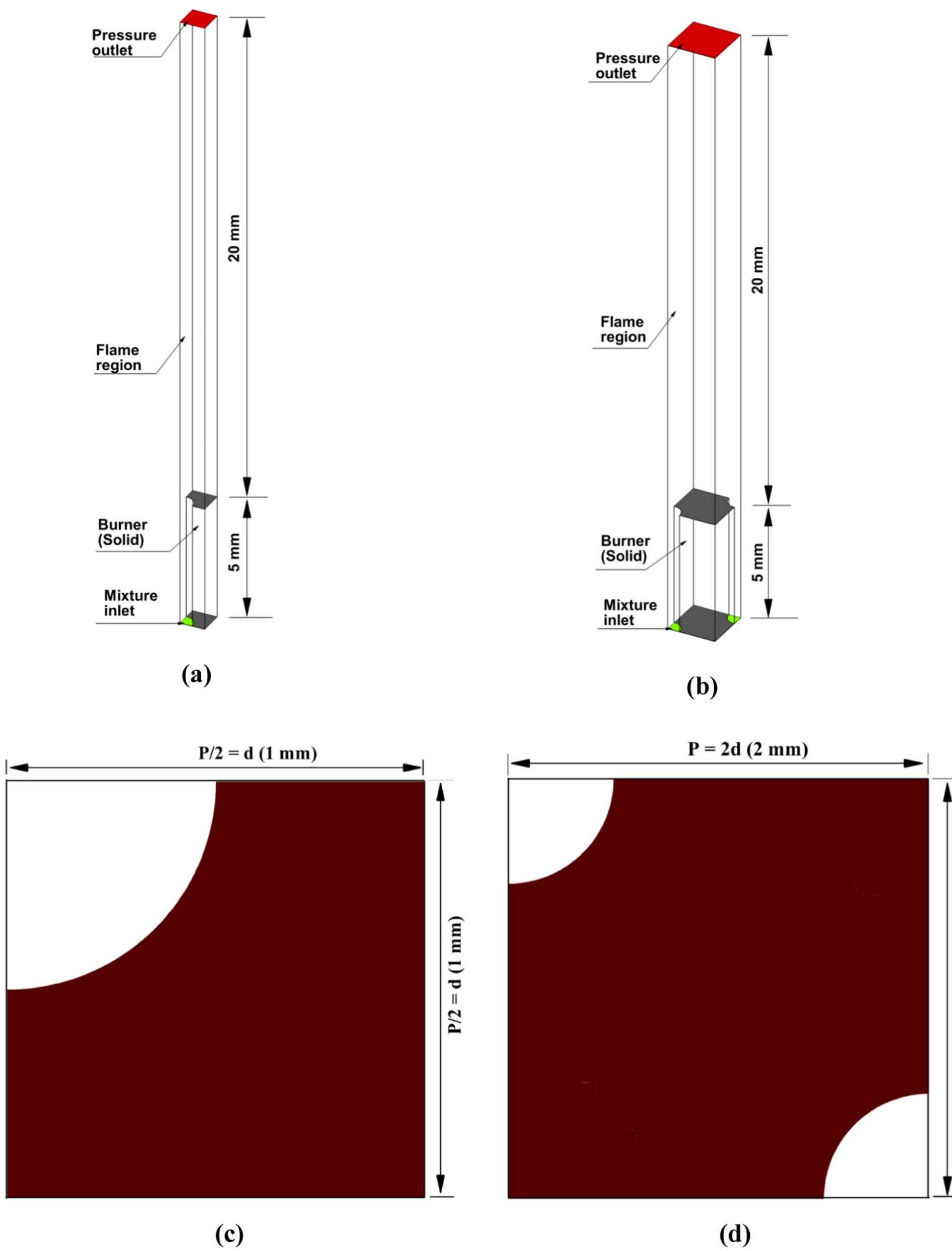

Fig. 1. The computational domain for (a) inline and (b) staggered configurations. The cross-sectional square for inline and staggered arrangement are shown in (c) and (d) respectively.

concluded that the flame structure cannot be predicted completely, with single step reaction mechanism. Recently, Rashwan et al. [17] performed an experimental study on partially premixed oxy-combustion flames anchored over a perforated plate burner. They could identify the range of oxygen fraction required for stable operation over a range of equivalence ratios. This experimental study also revealed the range of equivalence ratio over which stable flames were obtained at constant oxygen fraction of 36%.

With a significant improvement in computational resources and performance, numerical computations using detailed or reduced reaction mechanisms were attempted for predicting the flame structure and stabilization characteristics in a better and efficient manner. Altay et al. [11] presented a two-dimensional (2D) numerical model to predict the characteristics of premixed laminar perforated-plate methane-air flame, using a reduced kinetic model. With this model, they analysed the stabilization characteristics of perforated-plate burner flames under various operating conditions. Using the same 2D model, Kedia et al. [18] studied the flame response to enforced perturbations in velocity, with a detailed methane-air reaction mechanism. This study pointed out that a detailed exploration of flame-wall interaction is